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First results with the recoil separator ARES

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We present here the first results obtained with the new recoil separator ARES. ARES is used for the measurement of (p,γ) and (α,γ) reactions at astrophysical energies in inverse kinematic using both stable and radioactive beams.

1. MOTIVATION

The measurement of cross sections of charged-particle induced nuclear reactions at energies relevant for astrophysics are hindered by their small values. The study of reactions involved in explosive stellar events using radioactive beams still increases the experimental difficulties due to the lower beam intensities compared to those of stable beams. Therefore, new techniques and new intense beams are needed [1]. In order to enhance the detection efficiency, a recoil separator called ARES (Astrophysics REcoil Separator) has been recently built in Louvain-la-Neuve (LLN). ARES is coupled to the new cyclotron CYCLONE44, specially designed to produce intense ion beams at energies between 0.2 to 0.8 MeV/nucleon. The main application of ARES is the measurement of (p,γ) and (α,γ) reactions using both stable and radioactive beams and inverse kinematic. Taking advantage of the beams currently produced and accelerated at the CRC, several reactions of astrophysical interest will be studied using ARES, among them: ^{18}F(p,γ)^{19}Ne, ^{19}F(p,γ)^{20}Ne, ^{19}Ne(p,γ)^{20}Na, ^{7}Be(α,γ)^{11}C, ^{15}N(α,γ)^{19}F, ^{15}O(α,γ)^{19}Ne, ...

2. EXPERIMENTAL SET-UP

In order to be able to use short lived radioactive beams, inverse kinematic conditions together with a large detection efficiency for product detection, and a high rejection of the beam after interaction with the target, are required. The target consists of a thin ($50 - 150$ μg/cm^2) $(CH_2)_n$ foil -for (p,γ) reaction studies-, or a ^{4}He implanted foil -for (α,γ) reaction studies- (see next section). The reactions to be studied with ARES lead to the emission of relatively low energy γ-rays. Therefore, product nuclei are contained in a narrow forward cone ($\pm 1°$) around the beam direction. Furthermore, ARES has to

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separate the beam ions from the reaction products, both having the same momentum and, consequently, different velocities. The present setup results from extensive simulations [2,3] using different approaches (see Figure 1 in ref. [2]). The main components are: (i) a dipole magnet, used to select the most abundant charge state of the product; (ii) a Wien filter, that selects the velocity between the beam and the produced particles; (iii) a $\Delta E - E$ (gas) detector, which provides an additional separation power in Z; and (iv) a scattering chamber, used to monitor the beam properties by detecting the recoil protons and the scattered ions. Additionally, quadrupole doublet and triplet provide an adequate focusing of the product trajectories.

3. FIRST RESULTS

Before starting an extensive program of measurements, the beam transmission and the rejection power have been established. By using a 9.1 MeV $^{14}N^{2+}$ beam on a 60 $\mu g/cm^2$ C target, a rejection factor of 7×10^{-11} has been obtained as follows. Beyond the target, the most abundant charge state (5+), which represents about 50% of the beam, has been transported through ARES to a silicon detector, with an efficiency of more than 90%. Then, the ratio of the electric field to the magnetic field in the Wien filter was modified in order to transport the hypothetical ^{15}O that should result from the $^{14}N(p,\gamma)$ reaction; the other settings in ARES were unchanged. The remaining counts in the detector, in the area where the ^{15}O is expected, normalized to the beam intensity on the target are thus a measurement of the beam suppression factor. Later on, it was verified that this condition of the filter allowed to transmit correctly the reaction product, using a ^{15}N beam that was effectively transported through ARES. This suppression factor decreased by 3 orders of magnitude by using ΔE identification. The next step was the measurement of the resonant scattering process to the $J^{\pi} = 1^{+}$ resonance in ^{20}Ne at $E_{cm} = 635$ keV using a ^{19}F beam on a 150 $\mu g/cm^2$ $(CH_2)_n$ foil. Part of a Time-of-Flight spectrum is shown in Figure 1. The well-known interference effect between resonant and Coulomb amplitudes is clearly present.

Table 1
Percentage of retained/implanted ^{4}He in different Al (1 to 4) and C (1 and 2) foils.

Substrate	Implanted dose per cm^2	Retained/Implanted (%)
Al(1)	1.3 ± 10^{17}	47 ± 3
Al(2)	1.5 ± 10^{17}	41 ± 3
Al(3)	1.3 ± 10^{18}	11 ± 2
Al(4)	5.6 ± 10^{17}	30 ± 1
C(1)	1.3 ± 10^{17}	8 ± 1
C(2)	1.4 ± 10^{17}	10 ± 1

Finally, in order to study (α, γ) reactions, light self-supporting targets, resistant to the beam and with a sufficient density of the active element, are needed. Implanted ^{4}He

targets (Al and C foils, typically 50 $\mu g/cm^2$ thick) have been produced and analysed by Rutherford backscattering of protons [4]. The Al foils presented a higher content of ^{4}He after implantation (about 50%) than the C foils, for an implanted dose of about $10^{17} - 10^{18}$ atoms/cm^2. Table 1 summarizes the results.

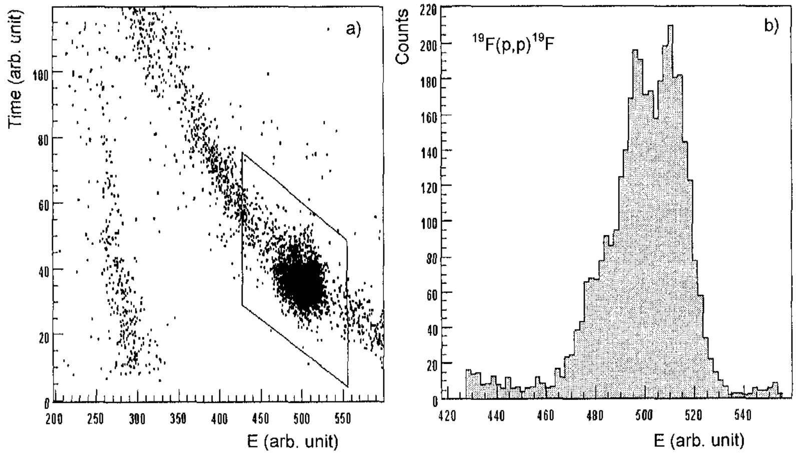

Figure 1. a) Part of a Time-of-Flight spectrum using a 13.1 MeV ^{19}F beam on a $(CH_2)_n$ target (see text). The area of the recoil protons is delimited. In b), the energy spectrum of these events, with the interference effect between resonant and Coulomb amplitudes, is shown.

4. CONCLUSIONS

The first results of ARES are very encouraging. The rejection power obtained is found to be sufficient for the study of several reactions of astrophysical interest using stable and radioactive beams produced at LLN. The measurements of the reactions $^{19}F(p,\gamma)^{20}Ne$ and $^{19}Ne(p,\gamma)^{20}Na$ are planned in the next future.

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